MORTALITY BY TIMING OF HIP FRACTURE SURGERY:

FACTORS AND RELATIONSHIPS AT PLAY

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Short title: surgical timing and mortality: other factors

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ABSTRACT

In hip fracture care it is disputed whether mortality worsens when surgery is delayed. This knowledge gap matters when hospital managers seek to justify resource allocation for prioritizing access to one procedure over another. Uncertainty over the timing-death association leads to either surgical prioritization without benefit or the underuse of expedited surgery when it could save lives. Discrepancy in previous findings results in part from differences between patients who happened to undergo surgery at different times. Such differences may produce the statistical association between timing and death in the absence of a causal relationship. Previous observational studies attempted to adjust for structure, process, and patient factors contributing to death, but not for relationships between structure and process factors, or between patient and process factors. In this article, we (i) summarize what is known about factors that influence, directly or indirectly, both timing of surgery and occurrence of death; (ii) construct a dependency graph of relationships among these factors based explicitly on the existing literature; (iii) consider factors with a potential to induce covariation of time to surgery and occurrence of death, directly or through the network of relationships, thereby explaining a putative timing-death association; and (iv) show how age, sex, dependent living, fracture type, hospital type, surgery type, and calendar period can influence both time to surgery and occurrence of death through chains of dependencies. We conclude by discussing how these results can inform allocation of surgical capacity to prevent avoidable adverse consequences of delaying hip fracture surgery.

INTRODUCTION

After breaking a hip, older adults face a high risk of death: 30% die within a year, with 7% dying during hospitalization.[1-3] The risk of in-hospital death depends on characteristics of patients, of their fracture, and of treatment.[4,5] Some also argue that delays to repair hip fracture may influence postoperative mortality by increasing patients' exposure to immobilization and inflammation.[6,7] Indeed, fewer deaths were reported among patients who underwent surgery within one or two days after hip fracture than among patients who waited longer for their surgery.[8-11] Findings from other studies, however, call into question whether mortality worsens with increasing time to surgery after hip fracture.[12-15]

This knowledge gap matters when hospital managers seek to justify resource allocation for prioritizing access to one procedure over another.[16] Aiming to prevent potentially harmful delays, several health systems have set short time frames for providing surgery to repair hip fracture.[17-19] Yet the surgery may be underprioritized at high-volume trauma centers due to competing demands for hospital resources.[20] Uncertainty over the timing-death association leads to either prioritization without benefit or the underuse of expedited surgery when it could save lives. Discrepancy in the findings of previous observational studies results in part from differences between patients in different surgical timing groups, which, if not controlled, may produce a spurious association between time to surgery and death.[21,22] For example, delays and deaths are more frequent for the procedure arthroplasty than for fixation.[23-25]

In health care evaluation, researchers attempt to control for such group differences by considering Donabedian's framework for factors related to structures and processes of care.[26] In this framework, the structures of care are the material resources (facilities, equipment, staffing ratios) and human resources (qualifications, experience) needed to provide care and the organizational features (systems, services, size, volume) of the care providers. The processes of care are medical procedures (diagnosis, treatment, rehabilitation) and managerial activities (transfer, scheduling, discharge planning) that constitute the care delivery within the defined structures. Shroyer et al. reasoned that patient factors (e.g. age, sex, comorbidity, socio-economic status) should be considered to estimate the effects of the structure and process factors on care outcomes.[27] Sobolev et al. further argued that delineating their effects also requires identifying two sets of relationships, those between care structures and processes and those between care processes and outcomes.[28]

Previous hip-fracture studies have controlled the association between surgical timing and death for structure, process, and patient factors, but not for the relationships between structure and process factors, or between patient and process factors.[8-15] A major reason for this omission is limited understanding of the network of relationships among factors which influence *both* time to surgery and postoperative in-hospital death. In this article, we offer an explicit description of relationships among the structure, process, and patient factors involved in worsening mortality after delayed hip fracture surgery in the form of a dependency graph.[29,30]

METHODS

We reviewed the literature for factors that influence the timing of surgery and separately for factors that influence postoperative in-hospital death after hip fracture surgery, using the Arksey and O'Malley scoping review framework.[31,32] The search strategies and study selection were described elsewhere.[33,34] Box 1 provides Pearl's classification of these factors according to their role in the putative timing-death association.[35] Table 1 lists factors influencing the timing of surgery and those influencing the occurrence of death, indicating whether other factors are also involved. Table 2 lists other factors producing variation in surgery timing and in-hospital mortality through a network of associations. The direction of association was determined from independent and dependent variable allocation in the regression analyses reported in the reviewed articles. Tables 1 and 2 further indicate whether factors are related to structures, processes, or patients.

Using Tables 1 and 2 entries, we constructed a dependency graph to represent relationships among the assembled factors. We interpreted an association as the *dependency* relationship based on mechanisms described in the reviewed articles. In the graph, nodes represent the factors and single-headed arrows represent the dependencies. The dependency graph is constructed on the premise that the timing-death association may result from the influence of common, mediating and intervening factors, rather than from any direct causal relationship. We first connected the "time to surgery" and "death" nodes with respective contributing factors. We then connected these two nodes with the common, mediating and intervening factors. At each step, we showed factors with a potential to induce variation in *both* time to surgery and postoperative in-hospital death through chains of dependencies.

DEPENDENCY GRAPH

Factors influencing time to surgery

Figure 1 shows factors influencing the time to surgery after hip fracture that are described in Table 1. In particular, the time to surgery depends on the treating hospital type[36-38] and its available resources, including operating rooms,[39-42] nursing staff,[43] surgeons,[39] specialists [23,44] and laboratory tests[23,41,44] Resource availability depends on the time of admission, with resources being less available "after hours" than during regular working hours.[42,45-47] The risk also depends on the type of surgery itself, because arthroplasty requires additional resources, such as a surgeon with arthroplasty experience and implants that may not be kept in stock.[3,23] The risk of a delay to surgery also depends on the overall demand for services, which may exceed available resources.[48] Delays may also occur if there is a need to transfer a patient before definitive care.[23] Finally, the time to surgery depends on the patient's fitness to undergo surgery.[15,40,44,49-51] Unstable medical conditions may delay the surgery appropriately, such as anticoagulation problems, volume depletion, electrolyte imbalance, uncontrolled diabetes mellitus or heart failure, or exacerbation of a chronic chest condition.[52,53]

[Insert Box 1 here]

Factors influencing in-hospital death

Figure 1 also shows the factors influencing in-hospital death after hip fracture surgery that are described in Table 1. The risk of death depends on age at admission,[54-56] pre-existing chronic conditions,[54,57] and fracture type.[58-60] The risk of death also depends on the surgery type, because of a greater chance of blood loss and anesthetic complications for patients undergoing arthroplasty than for patients undergoing internal fixation.[24,25] The risk of death also depends on the operating surgeon's skills, whereby patients treated by surgeons with a lower annual volume of hip fracture surgeries are more likely to die than those treated by surgeons with a higher annual volume of hip fracture surgeries.[61] The risk of postoperative death also depends on the occurrence of postoperative complications, such as pneumonia, myocardial infarction or acute heart failure.[62] Furthermore, the risk of in-hospital death depends on the length of time spent in hospital, which in turn depends on the presence (or absence) of early discharge policies.[3] The risk of death may also depend on where patients undergo treatment,[37,38] because of between-hospital differences in quality of care,[20] intensity of care,[63] clinical pathways,[42,64] and care standards.[20,65]

[Insert Figure 1 and Table 1 here]

Common factors

The type of hospital and type of surgery appear as factors influencing time to surgery and factors influencing in-hospital death. Figure 1 therefore shows these two factors which influence both sides of the timing-death association (orange nodes). First, hospital type produces variation in time to surgery through resource availability,[23,36,38-44] and variation in postoperative in-hospital death through quality of care, intensity of care, clinical pathways, and care standards.[20,37,38,42,63,65] Second, surgery type produces variation in time to surgery through resource availability,[3,23] and also produces variation in postoperative in-hospital death.[24,25]

Other dependencies

Figure 2 shows other dependencies among the factors that influence timing of surgery and postoperative in-hospital death, as described in Table 2. For example, fracture type depends on age at admission, with more older than younger patients presenting with intertrochanteric fractures.[58-60] The presence of chronic conditions[66,67] and postoperative complications[68] also depends on age at admission, with older patients presenting with more chronic conditions and complications than younger patients. Surgery type depends on the fracture type, with arthroplasty being the treatment of choice for femoral neck fractures[69] and fixation being the treatment of choice for intertrochanteric fractures.[70] The time of admission depends on the need for transfers before definitive care, because patients who are transferred are more likely to be admitted late in the day than patients who are admitted directly.[46]

Following inclusion of these other dependencies, we identified two additional factors that produce variation in both time to surgery and postoperative in-hospital death. First, age produces variation in time to surgery through fitness for surgery,[49] and also produces variation in postoperative in-hospital death through chronic conditions and complications.[66-68] Second, fracture type produces variation in time to surgery through surgery type,[69,70] and also produces variation in postoperative in-hospital death.[58-60] Figure 2, thus highlights four factors that produces variation in time to surgery and postoperative in-hospital death: hospital type, surgery type, age at admission, and fracture type.

Mediating factors

Figure 2 also shows postoperative complications as a mediating factor through which time to surgery may in part influence the occurrence of postoperative death. Delays may lead to complications and ensuing death through two underlying mechanisms: (i) immobilization, which can lead to potentially fatal complications, such as pulmonary embolism, pneumonia, and loss of muscle mass; and (ii) exposure to the inflammatory hypercoagulable state, which can also lead to potentially fatal complications, such as stroke and myocardial infarction.[6,7,12,71]

[Insert Figure 2, Table 2 here**]**

Intervening factors

Figure 3 shows intervening factors as described in Table 2, our extension of Pearl's taxonomy (Box 1). These factors may not be directly associated with time to surgery or postoperative in-hospital death, but they contribute to their variation through other dependencies. For example, age at admission depends on the patient's residence[72] and sex,[73] with men and those admitted from long-term care tending to be older than women and those admitted from home. The presence of chronic conditions depends on the patient's sex[60,66,74,75] and residence,[76] with men and those admitted from long-term care typically presenting with more chronic conditions than women and those admitted from home, respectively. Fitness for surgery depends on the patient's sex,[44] residence,[75,77] and socioeconomic status,[78] with men, those admitted from long-term care, and those from lower socioeconomic groups more likely to require medical stabilization before surgery than women, those admitted from home, and those from higher socioeconomic groups, respectively. Where a patients is treated determines the clinical pathway, and some pathways lead to more complications after surgery than others.[79] Resource availability depends on whether the prioritization places hip fracture cases over other urgent trauma cases.[20,41,80] Where implemented, policies on access to surgery have been intended to address a lesser priority for hip fracture surgery and shortened time to surgery in some hospitals.[3] The presence of an institution's access and discharge policy depends on the calendar period when a patient underwent surgery, conceptualized here as treatment era.[3]

Following addition of these intervening factors, we identified an additional three factors that may contribute to variation in both time to surgery and postoperative in-hospital death through chains of dependencies. Both sex and dependent living influence variation in time to surgery through fitness for surgery,[44,75,77] and also influence variation in postoperative in-hospital death through chronic conditions.[60,66,74-76] Treatment era influences variation in time to surgery through access policy, prioritization, and resource availability,[3] and also influences variation in postoperative in-hospital death through discharge policy and hospital stay.[3] Figure 3 thus highlights in orange seven factors that produce variation in time to surgery and postoperative in-hospital death: age, sex, dependent living, fracture type, hospital type, surgery type, and treatment era.

[Insert Figure 3 here]

DISCUSSION

In health systems when demand exceeds capacity, even urgent procedures, such as surgery to repair a broken hip, may be underprioritized. Yet, the health effect of surgical delay in patients with hip fracture remains disputed. In this article, we offer the phenomenology of worsening mortality after surgical delay among patients with hip fracture. We have synthesized the hip fracture literature concerning factors that may influence both time to surgery and postoperative in-hospital death, either directly or through intervening factors. The composite description of these factors and their dependencies is presented in the form of a dependency graph.

Previous research used Donabedian-Shroyer framework in the analysis of the timing-death association by inclusion of structure, process and patient factors contributing to in-hospital death.[8-15] Here we advanced that framework by considering two additional sets of dependencies: between structure and process factors, and between patient and process factors.[28] Collectively, these dependencies point to factors that may alter the association between timing of surgery and occurrence of death without influencing time to surgery and death directly. Failure to account for these dependencies may result in the conclusion that surgical timing and death are associated in the absence of true causation.[21]

We submit that future research should consider the timing effects within patient subgroups defined by factors inducing covariation of timing and mortality to strengthen attribution of mortality worsening to surgical delays.[81-83] The dependency graph presented here shows that age, sex, dependent living, fracture type, hospital type, surgery type, and treatment era can lead, through chains of dependencies, time to surgery and occurrence of death to vary in conjunction. Therefore, future studies should investigate the timing-death association separately for (i) older men undergoing arthroplasty after admission to community hospitals from long-term care with transcervical hip fracture and (ii) women in their 60s undergoing fixation after admission to teaching hospitals from home with intertrochanteric fractures. Comparing survival benefit of early surgery across these subgroups also informs effective resource allocation policy that targets patients who would benefit most from expedited access to hip fracture surgery.

The dependency graph provides a framework for further discussion of evidence gaps. In this article, the graph was constructed explicitly on the basis of existing literature. Therefore the absence of arrows between any two nodes could reflect the absence of knowledge rather than the absence of dependency, a convention adopted in causal diagrams.[84] For example, some researchers argued that patients' preferences may influence treatment decisions.[85] Indeed patients may postpone surgery to discuss treatment options with their caregivers. However, there is a notable paucity of evidence on the role of behavioural factors and social determinants in hip fracture care. Further, whether postoperative complications result from medical conditions that caused a surgical delay warrants exploration. Hospital type may influence mortality after hip fracture surgery because of variation in the health status of patient populations that use different hospitals. In the prediction context, Caillet et al used a dependency graph to discuss causal assumptions about variables that mediate effects of major risk factors for hip fracture occurrence.[30]

The dependency graph presented here shows dependencies among factors involved in worsening postoperative in-hospital death after delayed hip fracture surgery. Additional factors and dependencies may be at play for 30-day and 1-year mortality as patients receive care from multiple providers after discharge, with coordination and continuity of these services varying across regions. We also submit that many dependencies discovered in the context of hip fracture care may also apply to other fragility fractures.

CONCLUSION

The dependency graph, presented here, shows all known dependencies among structure, process and patient factors. Accounting for factors which produce covariation in timing of surgery and postoperative in-hospital death can strengthen causal attribution of mortality worsening to changes in surgery timing. Further, exploration of the association for subgroups defined by these factors will help to identify who benefits most from expedited access to surgery.

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FIGURES

Figure 1: Factors influencing time to hip fracture surgery (green nodes) and postoperative in-hospital death (blue nodes). Nodes represent factors reported in the reviewed literature. Solid arrows represent directional dependencies between nodes. Dashed arrow represents the putative association *in-hospital death* on *time to surgery*. Orange nodes represent common factors influencing both time to surgery and occurrence of death through chains of dependencies (orange arrows).

FIG1

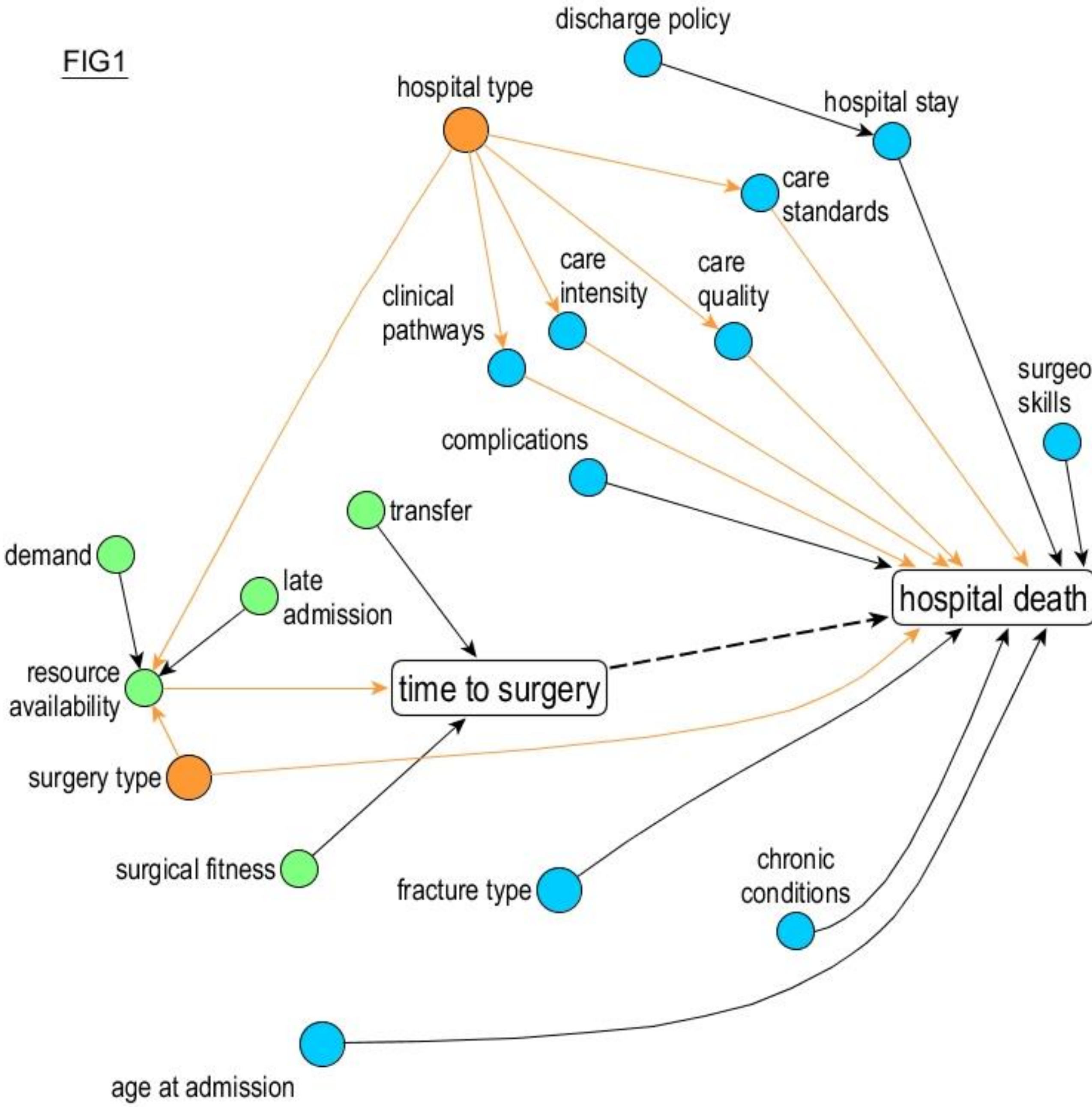

Figure 2: Dependencies among factors involved in the timing-death association, including complications as a mediator. Green nodes represent factors influencing only the timing of surgery. Blue nodes represent factors influencing only the occurrence of death. Orange nodes represent factors influencing both time to surgery and occurrence of death through chains of dependencies (orange arrows).

FIG2

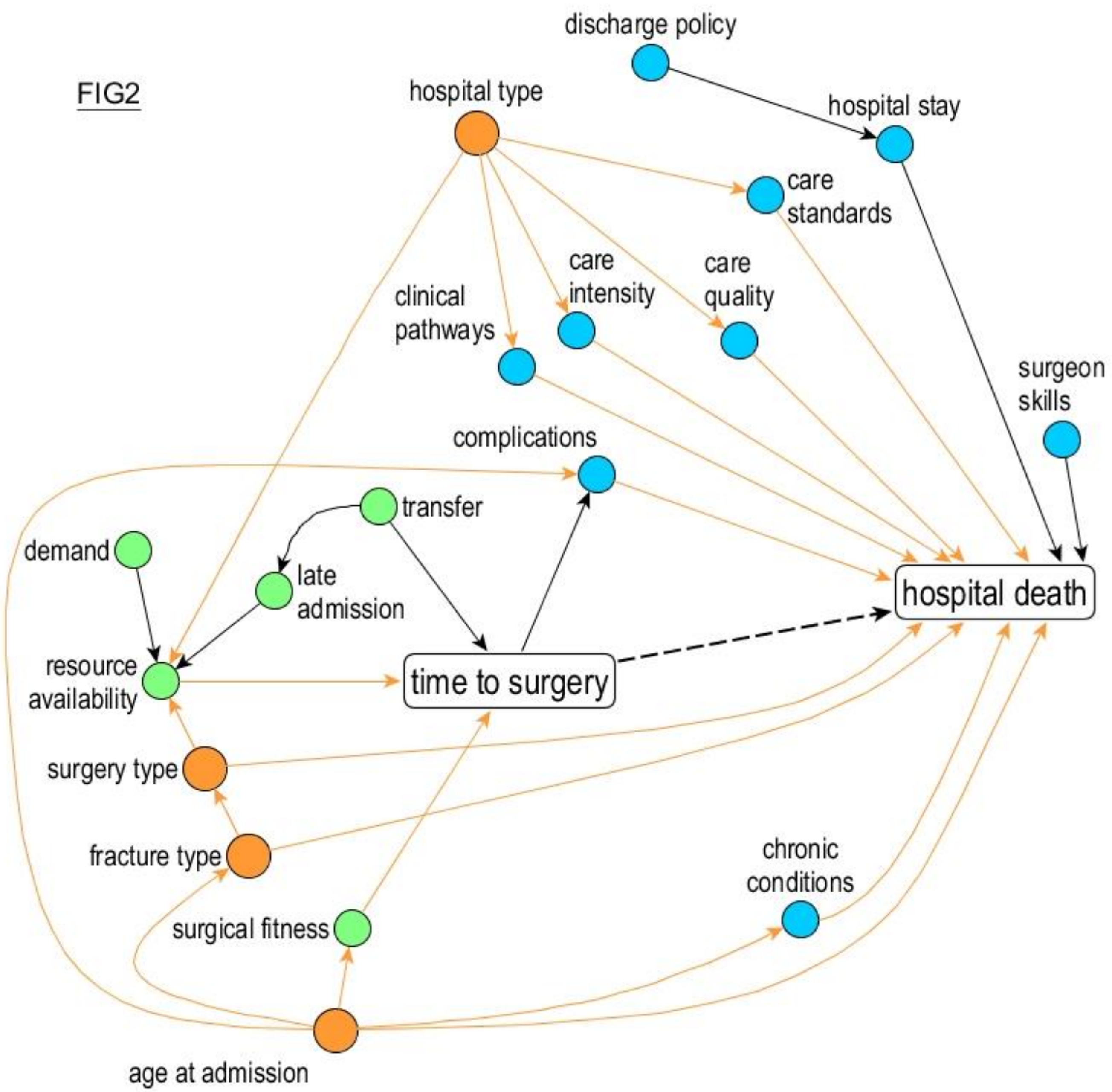

Figure 3: Dependency graph of all known factors and their relationships involved in producing the association between timing of surgery and postoperative in-hospital death after hip fracture. Orange nodes represent factors influencing both time to surgery and occurrence of death through chains of dependencies (orange arrows).

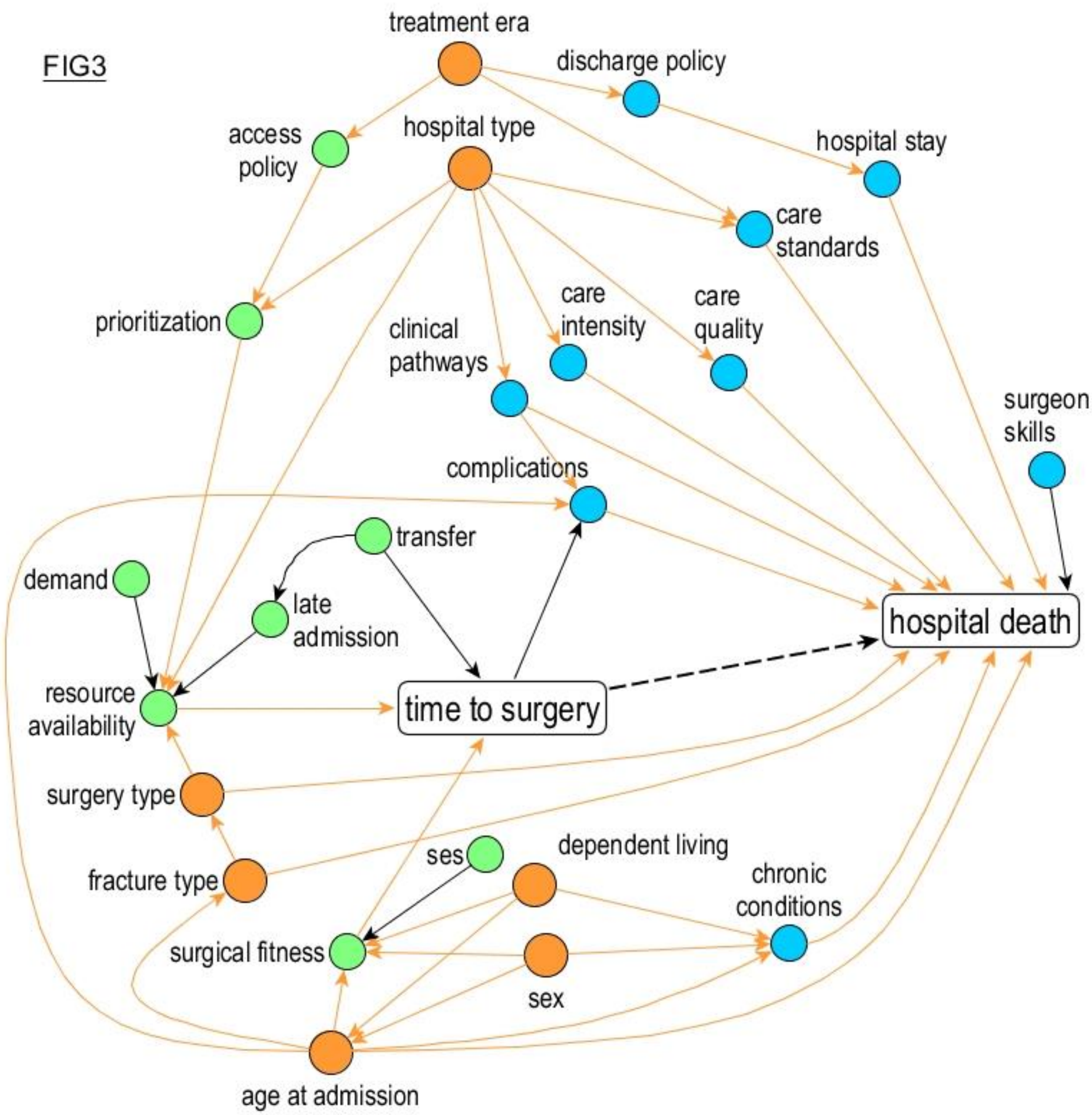

Table 1: Factors influencing timing of surgery and postoperative in-hospital death after hip fracture with indication of other factors involved[31,32]

Group of factors	Factors	Reported mechanism	Additional factors involved
Timing of surgery			
Patient	Surgical fitness	Physical status score by American Society of Anesthesiologists Classification is associated with a delay to surgery.[15,40,44,49-51]	
		Unstable medical conditions may appropriately delay hip fracture surgery.[52,53]	
Structure	Hospital type	Differences in resources between hospitals may lead to variation in exposure to an immobilized state, which in turn can lead to potentially fatal complications.[36-38]	Resource availability
Process	Resource availability	Limited operating room availability is associated with a surgical delay.[39-42]	
		Higher levels of nurse staffing improve operating room availability and shorten the time to surgery.[43]	
		Lack of availability of surgeons is associated with a delay to surgery.[39]	
		Waiting for completion of medical evaluations, family discussion, laboratory results, and fracture diagnosis all lead to a delay in surgery.[23,41,44]	
	Surgery type	Patients treated with arthroplasty may have a longer time to surgery than patients treated with fixation because of the need for more senior supervision or because implants are not kept in stock.[23]	Resource availability
	Demand	Waiting for space on an operating room list because of overbooking may delay surgery for patients who are otherwise medically fit for surgery.[48]	Resource availability
	Transfer	Transfer of patients is associated with a delay to surgery.[23]	
	Late admission	Patients admitted later in the day need to wait for resources to become available for surgery.[45]	Resource availability
		The effect of the day of admission is generally ascribed to a reduction in staffing levels during weekends and holidays.[42]	
		Patients admitted between midnight and noon are more likely to have surgery on the day of admission than patients admitted in the afternoon or evening on weekends.[46-47]	
Occurrence of postoperative in-hospital death			
Patient	Age at admission	Increasing age reduces the patient's reserve capacity necessary to cope with the double trauma of hip fracture and surgery.[54-56]	

	Chronic conditions	Comorbidity reduces the patient’s capacity to cope with the stresses of surgery and thus delays recovery.[54,57]	
	Fracture type	Patients with intertrochanteric fractures are more likely to be frail, develop anaesthetic related complications and die.[58-60]	
	Complications	The mortality rate among those with a serious medical complication after hip fracture surgery is higher than those without.[62]	
Structure	Hospital type	Lower use of recommended care processes at high-volume hospitals leads to death.[20]	Care quality
		Hospital staff members develop more effective skills if they treat more patients.[20]	Care standards
		Patients admitted to teaching hospitals in July, when inexperienced interns arrive, may be exposed to decision-making errors.[65]	Care standards
		Clinical pathways bring attention to hip fracture patients and their prioritization on operating room lists, which facilitates early access to surgery and is associated with better outcomes.[42,64]	Clinical pathway
		Treatment in hospitals with lower care intensity leads to death.[63]	Care intensity
	Surgeon skills	Low-volume surgeons may not select the appropriate procedure or preoperative planning, intraoperative technique, and postoperative management.[61]	
	Discharge policy	Policies introducing early discharge programs may lead to the death of patients outside of the hospital setting.[3]	Hospital stay
Process	Surgery type	The more extensive surgical and anesthetic requirements of joint reconstruction increase the risk of death relative to internal fixation.[24,25]	
	Time to surgery	Patients whose surgery is delayed are exposed to inflammatory and hypercoagulable states for longer than those whose surgery is not delayed.[6,7]	

Table 2: Dependencies among factors involved in the association between timing of surgery and postoperative in-hospital death after hip fracture.

Group of factors	Independent factor	Reported mechanism	Dependent factor
Factors influencing timing or death			
Patient	Age at admission	Patients with intertrochanteric fractures are older.[58-60]	Fracture type
		Comorbidity increases with age.[66-67]	Chronic conditions
		Age suppresses the immune response, which leads to complications and death.[68]	Complications
		Older adults more often require medical stabilization before surgery.[49]	Surgical fitness
	Fracture type	Intertrochanteric fractures are not treated with arthroplasty.[70] Femoral neck fractures are treated with hemiarthroplasty or arthroplasty.[69]	Surgery type
Process	Transfer	Patients who undergo transfer are more likely to be admitted to the treatment site later in the day.[46]	Late admission
Intervening factors			
Patient	Sex	Men present with more comorbidities than women.[60,66,74,75]	Chronic conditions
		Men more often require medical stabilization before surgery.[44]	Surgical fitness
		Among very elderly people, more women than men experience hip fracture.[73]	Age at admission
	Dependent living	Patients living in long-term care have more comorbidities than those living at home.[76]	Chronic conditions
		Older adults reside in long-term care.[72]	Age at admission
		Patients admitted to hospital from long-term care are more likely to require medical stabilization before surgery.[75,77]	Surgical fitness
	Socioeconomic status	The longer waiting times experienced by the most socioeconomically disadvantaged patients may, to some degree, be related to poorer baseline clinical condition, which could lead to a delay in surgery.[78]	Surgical fitness
Structure	Hospital type	Trauma center designation increases hospital workload, and hip fracture patients may be given lower priority than patients needing more urgent care in trauma centers.[80]	Prioritization
		Hip fracture patients may be given lower priority than patients needing more complex orthopedic surgery (e.g., patients with major trauma).[20]	Prioritization
	Treatment era	Policies introduced during the period when a patient is treated will influence the outcome.[3]	Access policy

		Policies introduced during the period when a patient is treated will influence the outcome.[3]	Discharge policy
		The calendar period when a patient was treated will influence the standard of care received.[3]	Care standards
	Prioritization	The availability of resources influences the prioritization of hip fracture surgery over other surgeries.[20,41,80]	Resource availability
	Access policy	Benchmark policies may lead care settings to prioritize hip fracture surgery over other surgeries.[3]	Prioritization
Process	Clinical pathway	Clinical pathways that include avoidance of weight-bearing activities postoperatively are associated with greater mortality than pathways that include full weight bearing.[79]	Complications
		Bed rest and restricted physical activity are associated with reductions in stroke volume, cardiac output, muscle mass/strength, bone mass, and oxygen uptake.[79]	Complications

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